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The 1938 Wheat Leaf-rust Epiphytotic in Oklahoma

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THE 1938 WHEAT LEAF-RUST EPIPHYTOTIC IN OKLAHOMA

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Introduction

Few Oklahoma records are available on which to base a comparison of the 1938 leaf-rust (Puccinia rubigo-vera tritici) epiphytotic with outbreaks of former years. The veteran wheat growers and wheat specialists who have been consulted have agreed that the 1938 outbreak was the earliest and most extensive which they can remember. Yet it is apparent that in the past the leaf rust has frequently been very prevalent in the state. Growers report that it has not been uncommon to find their clothes red with spores when passing through the fields of mature wheat, or to have the air filled with red spore dust at harvest. A few reports have been received of wheat which became so rusty in the fall that its value as pasture was considerably reduced. But in Oklahoma, as doubtless in many other wheat-growing states, both practical and professional agriculturists have come to look upon "red rust" as a common and harmless disease in contrast to the acceptedly dangerous "black rust". Black stem rust of wheat is rarely a disease problem in Oklahoma, but very few Oklahoma wheat growers and others interested in the crop realize that "black rust" in Oklahoma is nearly always the later stage of orange leaf rust.

The Weather Record (7)[1/]

Encouraged by the bountiful harvest and favorable price in 1937, the wheat acreage planted in the fall of 1937 mounted to about 14 percent above the acreage planted the previous year. In its fall development the wheat was subjected to an unseasonably cool and dry November and a cool December in which the rainfall was slightly below normal. Wheat was in fair condition by the end of November although its growth had been checked by low temperatures, and by the end of December the pastures were quite short and the crop was in need of moisture.

The first three months of 1938 were all abnormally warm, the departures from normal being +3.9°, +5.4°, and +7.3° for January, February, and March, respectively. Precipitation was approximately normal for January, but in February a 50-year record high began a period of excessive rainfall which was to carry through till harvest, the accumulated precipitation by

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1/ Numbers in parentheses refer to Literature Cited.

June 30 being 23.28 inches as compared with 16.86 inches for a normal year. The temperature and precipitation records for the months in question are included in Figure 1. In only three years during the past 47 (1889, 1908, 1915) has the average precipitation for January-June been as great as in 1938. The excess precipitation was not evenly distributed over the State. It was greatest in the east and in the large central wheat-producing belt. The extreme southwestern part of the State was rather dry, and true drought conditions prevailed in the western half of the Oklahoma Panhandle2/.

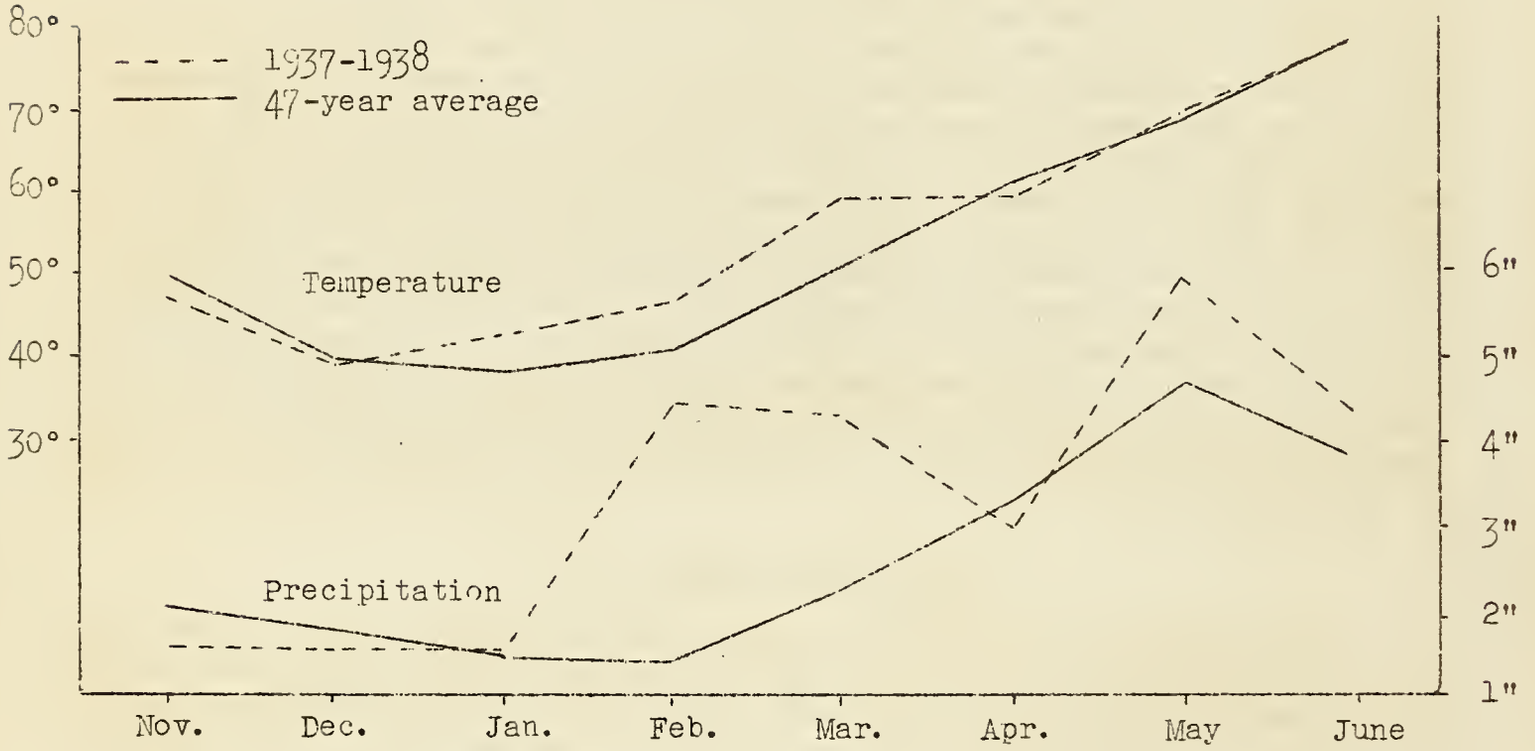

Figure 1. Average monthly temperature and precipitation for Oklahoma, 1937-38, as compared with the 47-year averages.

The only other outstanding feature of the meteorological record for the period in question was the series of sub-freezing temperatures in early April. During the opening week of April, late frosts killed back much of the earlier peaches and other fruits, and these were followed by an unprecedented 4-inch snowfall on April 7 and 8. However, the official Oklahoma weather report for April does not indicate general injury to the wheat crop as a direct result of the low temperatures. ("Wheat made rather rank growth and the crop was in good to very good condition at the close of the month,

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2/ For geographical references, see map (Fig. 2) under "Appendix".

although orange rust was prevalent throughout the state and was severe in the north-central and central counties." 7, Vol. 27, No. 4). The usual strong south winds prevailed throughout the spring. The 1938 hail damage to crops was $238,700 less than in 1937[3/]. Dust storms were frequent but were hardly a factor in wheat production except in the drought-ridden western half of the Oklahoma Panhandle.

It is commonly understood (2) that the conditions requisite to epidemic leaf-rust development include a sufficiency of overwintered inoculum, warm weather with an abundance of moisture in the spring, and an extensive acreage of susceptible wheat varieties. The foregoing meteorological account accords with this conception of predisposing factors. The mild winter permitted the rust to overwinter to a large extent, judging by the abundance of early spring infections. The warm temperatures and persistent rainfall throughout the spring permitted an unbroken series of secondary infection cycles from early spring until harvest. The ample moisture and the temperatures in the 60's from March until May stimulated the wheat to the rank, succulent type of growth most susceptible to the disease. Figures are not available on the acreage distribution by varieties, but it is known that large areas were planted with such susceptible varieties as Turkey, Blackhull, Fulcaster, and Cheyenne.

The Development of the Disease

It is regrettable that Oklahoma wheat fields were not examined for the presence of leaf-rust during the period of November 1937 to March 1938. No record of the disease in 1938 prior to the Oklahoma report of April 2 (P.D.R.[4/] 22: 115) has come to hand. A few days before this date a large amount of the rust was observed in fields in the vicinity of Stillwater, Oklahoma. The wheat was about 9 inches high, and was so heavily infected that the fields already looked yellow and scorched in spite of abundant rainfall. Although data were lacking for a comparison of this rust development with that of other years, cereal specialists consulted were of the opinion that the rust was abnormally early in its appearance. This is in accord with the unusually early appearance of oat crown rust [P. coronata] (P.D.R. 22: 117, 135) and stem rust [P. graminis] (P.D.R. 22: 137) in Texas, of leaf rust, crown rust, and stem rust in Kansas (P.D.R. 22: 143, 242), of crown rust in Arkansas (P.D.R. 22: 181), and of stem rust in Oklahoma (P.D.R. 22: 157).

On April 23 and 24, 98 wheat fields were examined along a circuitous route through the major wheat sections of the west-central part of the State (P.D.R. 22: 133). Leaf rust was found in abundance at nearly all points. The region of greatest damage was in the west-central area from El Reno to

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3/ Figures obtained by totalling crop losses due to hail as reported in (7), March to July, 1937 and 1938.

4/ Here and elsewhere in this paper "P.D.R." refers to the Plant Disease Reporter.

Enid, the heaviest wheat-producing region of the State. At this time an average of 30 percent of the leaves had been destroyed while in many fields the leaf-damage had reached 40 to 50 percent. The remaining leaves were for the most part thickly spattered with the tiny yellow flecks marking incipient rust destruction. But the color of a wheat field is the color of the uppermost leaf or two, and as these leaves were still green the fields from a distance showed a false appearance of healthy, vigorous condition. Very little of the wheat had begun to head, and from the presence of the incipient lesions it was apparent that the trouble would soon assume a more menacing aspect.

During the following week, April 24 to 30, the rust became obvious with a spectacular suddenness. Fields which a few days previously had been a rich, dark green were now rapidly turning yellow, as the last leaves died before the production of heads, and six to eight weeks before harvest. The striking change led one seasoned crop scout to refer to the appearance of the fields as "death pallor". This condition involved half the wheat in the State. It prevailed generally over the State except in the fields of rust-resistant wheat varieties and in the drier regions around Woodward and westward into the Panhandle.

At about this time growers and millers became concerned about the trouble and unsolicited letters began to pour in asking for information on the trouble and prospects of crop damage. A letter was sent to all county agents acquainting them with the situation, and requesting information on the progress of the disease. The following excerpts from letters are instructive:

> "There has not appeared to be much apparent damage up to about a week ago. Now, however, an increasing number of farmers have been coming into the office reporting rust in their wheat. The apparent damage has been increasing rapidly within the last few days. Fields that were a good healthy dark green a week ago are heavily tinged with orange at present. In all fields I have examined there seems to be some rust, at least in the lower leaves. However, in the majority of fields there is no apparent damage up to now. It does seem, though, that the complexion of these fields has been changing rather rapidly in some instances."--Charles Gardner, County Agent, Taloga, May 3, 1938.

> "Wheat in this community seems to have been deteriorating in the last few days."--E. O. Swaim, Mgr., Blackwell Coop. Elevator, Blackwell, May 3, 1938.

> "Rather heavy damage looks almost certain."--A. R. Garlington, County Agent, Pawnee, April 26, 1938.

"The rust seems to be worst in bottom land and this on the Burtschi farm has probably damaged the crop 80 percent. The damage on the Bob Wheeler farm was about 50 percent. Rust has caused about 30 or 40 percent damage to bottom land wheat throughout Grady County. It is not damaging the wheat seriously on upland."--Lant Hulse, County Agent, Chickasha, April 30, 1938.

"I am enclosing some samples taken from a 30-acre wheat field in Fitzhugh, Oklahoma. This field of wheat I am sure is worth nothing for a grain crop and feel sure that it will be turned under within the next few days and prepared for another feed crop."--J. B. Hill, County Agent, Ada, May 3, 1938.

And the following characteristic account May 3 from the manager of a large flour mill, who is anonymous by request. Typography as in the original.

"I have been going into the city to see the ball games, and as driving along the road I would notice the growing wheat. It all looked nice and green from the road that I take to avoid traffic. As stated the wheat looked nice and green. However when coming home Sunday afternoon I again noticed the wheat and Monday morning I told Mr._____ that the wheat was already starting to turn and it would not be long now before harvest. The wind was blowing and the wheat was waving and I noticed it all had a shade of light yellow. Well, Monday evening I went out to those fields and while they were turning yellow all right yet THEY WERE NOT RIPENING FOR THEY HAVE NOT EVEN HEADED OUT YET. That yellow that I saw from the road was dead leaves and not headed wheat starting to ripen."

A second trip through the State, following a route similar to that of April 23 to 24, but extending farther into the Northwest section, was made on May 7, 8, and 9 (P.D.R. 22: 157). The heads were now beginning to emerge, and here and there a field was fully headed, although the grain had not yet started to fill. The emergence of the green heads brought about another sudden transformation in the appearance of the fields. Fields which a week ago were yellow and scorched were now rapidly regaining a green luxuriance, and with this change the fears of the farmers rapidly subsided. Few understood the vital relationship of the leaves in providing the necessary substances for the filling of the kernels, or realized that their wheat crop of 1938 was an attractive superstructure without an adequate foundation.

Pathologically, the situation was that of the end of April, with the further developments that might logically have been expected. The inconspicuous pin-point infections of the upper leaves had now developed into destructive pustules, until in many fields the last remnant of leaf tissue had been killed before the heads emerged. Stem rust was just appearing in the central part of the State at this time. (P.D.R. 22: 157). The area of greatest leaf-rust infection coincided with the area of greatest wheat production in the State, a band beginning at Grady and Caddo Counties and extending northward with increasing damage through Canadian, Blaine, Kingfisher, Garfield, and Grant Counties, and thence into Kansas. (See map, Figure 2, in "Appendix").

To the west of this area the disease decreased with the decrease in rainfall. Wheat in Woodward County was showing 1 to 5 percent infection when wheat from Canadian to Grant Counties was 30 to 50 percent infected. The northwestern counties received more than their share of the late spring rains, and by harvest time the wheat in this area was heavily infected. Nevertheless, the damage to the crop was not great because of the lateness of the rust attack. Beaver County in the Panhandle, adjoining the drought area, completely escaped the disease.

In the southwestern part of the State the rust infection was only slightly less severe than in the central part, except in Jackson, Harmon, Greer, and Beckham Counties at the extreme west, where dry weather was the limiting factor. The wheat in the southwestern counties also received more than its share of injuries from other causes, in particular from army worms, brown mites, frost, and hail.

East of the main area of infection, the disease was irregular in its distribution and severity. The principal factors concerned in the irregularity appear to be the isolation of many of the fields, the frequent use of leaf-rust resistant varieties, and the absence of any great wheat tract to the southward.

A third trip over the same area was made at the end of May with Dr. H. A. Edson (P.D.R. 22: 179). At this time the wheat had begun to fill, and although most of the leaves were long since dead, the rust was indicating its presence by pustules on the glumes and awns, and its effect by the short, poorly-filled heads which were everywhere in evidence. Stem rust could be found without difficulty, but usually in very small amount.

If at this point the crop had matured at a normal rate, the rust damage might have been even greater than it was. But the spring rains continued into June, and harvest was consequently delayed. During this extended period the stems, glumes, and awns were able to contribute toward the filling of the grains, and to a small extent compensate for the early loss of the leaves. The rains also served as a deterrent to farmers who sometimes have a tendency to harvest earlier than is necessary.

Letters to the Plant Pathology Department, which had become less frequent during the early heading stage, were now again received in quantity. They were mainly concerned with the reason for the small heads, poor fill, and shriveled grain in wheat which had looked so promising a short time before. In some cases growers inquired about the advisability of saving 1937 seed for planting the 1939 crop. (Many did so on their own initiative). Occasionally a letter was received requesting information on the safety of feeding rusted wheat to livestock. On two or three occasions wheat growers were disturbed because their wheat kernels were strikingly orange-discolored at the tip. The discoloration proved to be due to masses of leaf-rust uredospores which were entangled in the brush of the grains.

Varietal Susceptibility

An account of the behavior of wheat varieties with respect to the leaf-rust in 1938 is restricted to data available from county agents' and millers' reports, from inspection of the wheat variety plantings of the Oklahoma Agricultural Experiment Station, and from personal field observations, which latter were often limited by ignorance of the variety observed.

Of the major hard wheats grown in Oklahoma, Turkey and Blackhull were severely attacked, while Chiefkan gave evidence of considerable resistance. Tenmarq showed resistance in some localities. It was not fully resistant, and occasionally it was severely attacked, but on the whole it did not show the susceptibility of Turkey and Blackhull. The rust-resistance of Chiefkan should not be taken as a recommendation for its use, because Chiefkan has proved disappointing in other respects. Its appearance of high quality is deceptive, and it is not certified by Kansas or recommended by the Kansas Agricultural Experiment Station or the Oklahoma Crop Improvement Association. It is not considered acceptable from the milling and baking standpoints (5).

Among the soft wheats, Kawvale and Mediterranean (Bluestem) proved relatively resistant, while Red Cross and many other soft wheat varieties were severely attacked.

Through the kind cooperation of Professor C. B. Cross and Walter Chessmore, the following reactions, based on readings in the Stillwater Agronomy plots, have been made available. As they are taken from rather small plantings in a single locality, they are given as suggestions rather than as final.

Resistant Varieties	Moderately Resistant	Moderately Susceptible	Highly Susceptible
Kawvale	Superhard	Defiance	Java
Iowin	Golden Cross	Turkey	Mammoth Red
Sherman	Nittany	Pilcraw	Purplestraw
Marvel	V.P.I. 131	White Federation	Rice
Red Russian	Valley	Bunyip	Cheyenne
Currawa	Ghirka	Onas	Surprise
White Winter	New Zealand	Eaton	Oregon Zimmerman
Wilhelmina	Lofthouse	Prohibition	Rink
Wisconsin Pedigree #2	Quality	Blackhull	Touse
Chiefkan	Greeson	Converse	Early Defiance
	Martin	Red Indian	Fulcaster
	Eagle Chief	Forward	Little Club
	Yogo	Prosperity	
	Pacific Bluestem	Walker	
	Early Blackhull	Leap	
	Harvest Queen	Purkof	

Other Factors Affecting the 1938 Crop

An analysis of the various factors influencing yield and quality of any crop in any year, is at best the weighed opinion of those who have carefully studied the crop in its development. This was particularly true as respects the Oklahoma wheat crop of 1938, where the factors were intense and sometimes diametrically opposed in their influence on the crop. Some of these factors are measurable. We can calculate with fair accuracy the damage due to hail, to smuts, or to army worms. Losses from leaf rust can be estimated with reasonable accuracy by reference to the measurements that were developed in the work of Caldwell et al., and of Johnston and Miller (1, 3). The effects of other factors, such as excess moisture, long-postponed after-effects of frost, and late attacks of stem rust are more conjectural.

The meteorological factors influencing the 1938 crop were primarily growing temperatures, frost, moisture, and hail. As regards growing temperatures, these were in the main beneficial to wheat growth. Temperatures in the vicinity of 65° F., favorable for wheat development, were reached early in the season and sustained throughout the greater part of the spring. With regard to hail, figures for the injury to wheat alone are not available, but the total hail injury to crops in the spring of 1938 amounted to $1,563,000 as compared with $1,801,700 for 1937[5/], which is not excessively high.

5/ See footnote 2, page 2.

The spring precipitation, which is often the limiting factor in Oklahoma wheat production, was ample, in most of the State, for successful wheat development. It was not excessive as measured against the optimal requirements for wheat growth, except as it affected the wheat diseases, delayed the harvest, or caused local flooding of low fields. The effect of the late spring frosts was largely a temporary set-back, although permanent injury to the heads of Early Blackhull wheat was evident, especially in the southwestern counties. These various meteorological factors are discussed in their relation to yield reduction on pages 15 to 17.

With regard to the effects of insects on the 1938 wheat crop, the principal features of the season were (a) a severe local infestation of brown mites in the extreme southwestern counties, (b) an abortive outbreak of grasshoppers which failed to be as destructive as was anticipated, (c) generally scattered infestations of army worms, (d) numerous local infestations of the green bug in the early spring, which were checked by rising temperatures in April, (e) a light infestation of stem maggots, which were found at many points over the State but never over 1 percent in the fields, and (f) an increasingly important attack of the wheat white grub especially in the northern counties. Of all these, the army worms were most destructive. At the time of their greatest activity the wheat leaves had been largely destroyed by rust, and hence their attack was directly on the heads, which accentuated the damage. All in all, the losses in wheat from insect depredations in 1938 were no greater, and possibly less than in an average year.

Dr. F. A. Fenton, Oklahoma State Entomologist, after reading the foregoing paragraph has kindly consented to add the following comments on the entomological aspects of the 1938 wheat crop:

> "Your summary of wheat insect conditions for Oklahoma is correct. According to Mr. Stiles' grasshopper report, I have the following figures on the wheat crop: 134,249 acres damaged. Loss in dollars - $598,439.96. Acres protected - 585,305. Savings in dollars $2,363,746.18. This is the report which Mr. Stiles has compiled from a questionnaire sent to county agents.
>
> "The wheat white grub, Phyllophaga lanceolata, caused many hundreds of acres of wheat to be replanted to this or other crops. In most cases the wheat was destroyed as many times as it was replanted. Where it was felt that there was enough wheat left so that replanting was not necessary, such fields were usually undisturbed but the grubs continued their work so that there was an important crop reduction, the extent of which we have been unable to determine."

The principal diseases affecting the 1938 wheat crop, apart from leaf rust which overshadowed all others, were bunt [Tilletia spp.], loose smut [Ustilago tritici], and stem rust. According to the Federal Grain Market Inspection (6) bunt was less prevalent in Oklahoma in 1938 than in 1937. Loose smut was everywhere in evidence (P.D.R. 22: 206) with an average loss for the State of about 2.5 percent. This does not appear to represent a significant change from 1937 or earlier years. Slight amounts of basal glume rot [Bacterium atrofaciens], foot-rots, speckled leaf blotch [Septoria tritici], Helminthosporium infections, scab [Gibberella saubinetii], and mosaic [virus] were observed, but none of these was a yield factor of importance. Stem rust appeared in traces at heading time. By harvest it was fairly prevalent, but appeared to be a yield factor in only exceptional cases. (P.D.R. 22: 180. See also discussion on page 15 following).

Lodging was fairly frequent, due in some cases (mainly in the early wheat of the southwestern counties) to frost injury, in other cases to delayed harvest as a result of June rains, and in many cases to weakness of the straw as a result of the starved condition following the loss of leaves from leaf-rust.

The Yield

The average Oklahoma wheat production for the 11-year period from 1927-1937 was 46,000,000 bushels. This includes several years of drought. The 1937 production was 65,462,000 bushels from 4,610,000 acres harvested, an average yield of 14.2 bushels per acre. In 1938 the production was 58,993,000 bushels, or an average of 11.0 bushels per acre. The 1938 yield was thus 22.5 percent less than in 1937 on an acreage basis. It was below the average yield per acre for 1927-1936, which includes the drought years.

Not only was there a decline in the amount of the production, but a further loss resulted from a lowered quality of the 1938 wheat. The Federal Grain Inspector's office at Enid reports on the 1938 crop as follows (6): "The test weight and appearance of the Hard Red Winter wheat of Oklahoma is below that of the past few years. The average test weight is about 57.7 pounds as compared to 59.7 to 60.2 pounds in past years."

Additional evidence on the yield and quality of the 1938 crop was obtained directly from the farmers by means of a questionnaire distributed by county agents in June. Typical reports from a few of the more important wheat-producing counties are given in Table 1, complete and in the exact form received, except that the growers' names are omitted.

The outcome of threshing returns is brought out in the following items from local Oklahoma newspapers:

"Farmers in the Enid wheat belt, harvesting as little as three bushels per acre from fields that looked as if they would produce thirty bushels, predicted today the Oklahoma wheat crop would fall far short of the government's June 1 estimate."

"Harvest returns from the southwest continued disappointing in some sections, Enid millers suggesting the Oklahoma crop would fall 30,000,000 bushels or more below the recent government estimate of 72,000,000."

"There are no well-filled wheat heads this year. Some are empty at the bottom, and others at the top, and some have no grains at all. Wheat is testing between 45 and 61 pounds."

"From Fairview, comes expressions from farmers that 'Our wheat is not half as good as we were thinking it was'. Grain is shriveled and light in weight, it was reported in that area."

The price of wheat, in its continual decline since the dollar-a-bushel level for the 1937 crop, was twice temporarily raised, once when the rapid development of rust was first apparent, and again on news of the disappointing threshing returns in the southwest. But the forces determining the price of wheat in 1938 were not entirely related to production, and the unexpected losses in the United States winter crop could have no more than a transient superficial effect on the price.

Leaf Rust as a Factor in the 1938 Yield Reduction

During the earlier part of the growing season of 1938 there was every indication of a most bountiful harvest. Moisture and temperature were favorable; the acreage was large. This was reflected in the optimistic wheat yield predictions for Oklahoma which ran as high as 77,000,000 bushels. The Oklahoma all-time high is 74,000,000. The leaf-rust infection caused the Oklahoma Agricultural Experiment Station to inject a note of conservatism into this picture in April, with an estimate 30 percent under the more optimistic predictions, but even as late as June 6, at the threshold of harvest, official estimates were still running as high as 72,500,000. The actual yield was 58,993.000 bushels of low quality wheat.

This unexpected result necessitated interpretation, particularly on the part of the sponsors of the higher estimates. The theories advanced were numerous and varied. To one crop scout the lowered yield was due to "root-exhaustion and rot". To another it was "frost and poor foundation conditions". A third attributed it to "freeze and stem rust and continued rains". A fourth considered it due to "subsoil dryness". A fifth, on April 27 held that "neither stem rust nor orange rust will be of much consideration", although on June 20 he reported "serious retrograding from shallow rooting and orange rust". A local agronomist felt that insects

Table 1. Representative Farmers' Reports on the 1938 Wheat Crop.

	County	Location of field	Upland or Bottom	Wheat Variety	Yield in 1938	Yield in 1937	Test weight in 1938	Test weight in 1937	Growers' Comment
1.	Blaine	Eagle City	Both	Early Blackhull	5	25	54	60	Lots of rust. Lots of shriveled grain.
2.	"	Geary	Upland	Superhard Blackhull	6	20	53	60	Lots of rust. Lots of shriveled grain.
3.	"	Watonga	Upland	Superhard Blackhull	11	21	53	60	Lots of rust. Lots of shriveled grain.
4.	"	Watonga	Upland	Tenmarq	35	First Year	58	--	Very little rust. Not shriveled.
5.	"	Watonga	Bottom	Tenmarq	30		58	--	Very little rust. Not shriveled.
6.	"	Watonga	Bottom	Superhard Blackhull	12	28	53	60	Lots of rust. Lots of shriveled grain.
7.	"	Omega	Upland	Superhard Blackhull	10	12	56	60	Lots of rust. Lots of shriveled grain.
8.	"	Omega	Upland	Tenmarq	22	1st yr.	58	--	Very little rust. Not shriveled.
9.	"	Eagle City	Upland	Chiefkan	20	21	60	60	Very little rust. Not shriveled.
10.	"	Eagle City	Upland	Early Blackhull	12	21	55	60	Lots of rust. Shriveled.
11.	Garfield	Drummond	Upland	-----	11	22	57	63	Leaf rust, shriveled kernels, some hail, and too much moisture on flat land.
12.	"	Hunter	Upland	-----	10.5	18	56	59	Plenty of rust. 8.3% hail.
13.	"	Carrier	Upland	Blackhull	4	28.5		60	Leaf rust, some smut, worms, late freeze, too much rain.
14.	"	Garber	Upland	-----	8	17	57	60	Rust and grubs.
15.	"	Garber	Bottom	-----	15	18	54	60	Rust.
16.	"	Kremlin	Upland	Turkey	11	17.5	56-58	60	-----
17.	"	Carrier	Upland	Tenmarq	8	29	56-57	60	-----
18.	"	Marshall	Upland	-----	12	15	59	60	Some rust and lodging.

	County	Location of field	Upland or Bottom	Wheat Variety	Yield in 1938	Yield in 1937	Test weight in 1938	Test weight in 1937	Growers' Comment
19.	McClain	Byers	Upland	Hard Winter	10	18	59	61	Trace of leaf rust. Yellow berries.
20.	"	Newcastle	Upland	Hard Winter	20	30	59	61	Yellow berries. Leaf rust.
21.	"	Newcastle	Upland	Hard Winter	21	30	60	61	Yellow berries. Leaf rust.
22.	"	Newcastle	Upland	Hard Winter	14	20	60	61	Leaf rust and yellow berries.
23.	"	Newcastle	Upland	Hard Winter	30	30	61	62	Leaf rust.
24.	"	Newcastle	Upland	Hard Winter	25	32	54	60	Leaf rust.
25.	"	Newcastle	Upland	Hard Winter	25	39	59	61	Leaf rust.
26.	"	Purcell	Bottom	Hard Winter	31	38	60	62	Leaf rust, army worms.
27.	"	Newcastle	Upland	Hard Winter	16	18	58	60	Yellow berries, rust.
28.	"	Goldsby Store	Upland	Hard Winter	17	32	54	60	Yellow berries, rust.
29.	Canadian	29-14-9	Upland	Turkey Red	12	21	59	60	Leaf rust and stem rust damage. No worms.
30.	"	Heaton Com.	Upland	Tenmarq	17	25	58	60	Rust damage.
31.	"	22-14-9	Upland	Blackhull	16	21	60	58	Down in top joint. Leaf rust bad. Some stem rust.
32.	"	5-13-6	Upland	Tenmarq	15	18	60	58-61	Frost damage. No worms. Leaf rust.
33.	"	2-12-9	Upland	Fulcaster	16	18	59	60	Leaf rust and some stem rust. No worm damage.
34.	"	12-11-8	Upland	Fulcaster	16	15	58	63	Leaf rust, freeze damage, no stem rust, no worms.
35.	"	21-11-8	Bottom	Fulcaster	20	30	58	62	Leaf rust, freeze, stem rust, worms bad.
36.	"	7-12-6	Bottom	Unknown	18	20	58	60	Worms bad, leaf rust, stem rust, broke over.
37.	"	32-12-5	Upland	Turkey Red	9	16	59	60	Leaf rust bad, some stem rust, freeze, 30% damage.
38.	"	12-13-9	Bottom	Turkey Red	18	26	58	60	Worms bad, leaf rust bad, stem rust damage bad.

were the only major cause of lowered yields. Several authorities have cited as causes leaf-rust, stem rust, excess moisture, late harvest, insects, hail, and April freeze, without pointing out the relative importance of any of these. Of all, the explanations occurring most frequently are leaf-rust, April freeze, stem rust, and excess moisture. The year 1938 was an off-year for wheat insects, hail damage to crops in Oklahoma in 1938 was $238,700 less than in 1937[6/], and the remaining factors suggested are too vague to be susceptible of analysis.

It is now possible to analyze these factors and gain some information on their relative rôles.

1. Leaf-rust. It has become apparent from observations and reports that in 1938 the best yields were generally those of the leaf-rust resistant varieties, and that the rust-susceptible varieties showed the poorer yields and quality of grain. This was particularly evident when resistant and susceptible varieties were grown on the same farm and subjected to the same conditions of temperature, moisture, soil, culture, hail, and insects. For example, in Table 1, reports 3 and 4, 5 and 6, 7 and 8, and 9 and 10 in each case were pairs of reports from the same farm.

The areas of poorest yield and quality of grain in 1938 were the areas of greatest leaf-rust infection, viz. from Grant County southward. The northwest area, where leaf-rust was latest and lightest, produced the best yields and quality of wheat in the State, although this area had its share of frost, hail, late rains, and army worms.

It has been shown in Kansas, Indiana, and elsewhere (1, 3, 4) that the removal of wheat leaves by leaf-rust has a definite and predictable effect in lowering the yield and quality of wheat, and that this effect is greater or less according as the infection takes place at an early or late stage in the development of the wheat. These studies have shown experimentally that infection of susceptible wheats by leaf-rust at a time and to a degree comparable to those of the Oklahoma epidemic, has the following effects on the wheat: reduction of the yield from 30 to 50 percent or more; rapid and severe deterioration of the roots; reduction in test weight and in protein content of the grain; production of yellow berry; and in some cases shriveling of the grain. The yield reduction results from the production of shorter heads with fewer and smaller kernels. On this experimental basis it was possible to predict in late April that the Oklahoma crop would show the foregoing results, and the appearance of the plants and grain at harvest time was a faithful and fully-detailed expression of these same effects.

6/ See footnote 2, page 2.

2. Stem-rust. A number of surveys have shown that although stem-rust arrived early, it did not become well established in Oklahoma until harvest time, and that except in rare cases it was not a major factor in yield. (Cf. P.D.R. 22: 180). Reports compiled from the summaries of the Bureau of Entomology and Plant Quarantine, and the "Cereal Courier" (P.D.R. 22: 285) estimate the Oklahoma damage from stem-rust in 1938 at 2 to 5 percent of the crop. The average farmer does not distinguish leaf-rust from stem-rust. To him leaf-rust is "red-rust" and is harmless; stem-rust is "black-rust" and is dangerous. Oklahoma wheat fields were filled with "black rust" at harvest time, but it was the black telial stage of the orange leaf-rust, and not a destructive amount of black stem-rust. This misconception often extends beyond the farmer to professional agriculturists. The "stem rust" or "black rust" reported here and there in Table 1 is undoubtedly the telial stage of leaf-rust in some or many of the cases, judging by personal experiences in the farmer's diagnosis of his wheat rusts.

Moreover, it is the tendency for an observer to judge the causes of crop loss in terms of the conditions existing at the time the damage is noted. Leaf rust did its destructive work in Oklahoma in April and May, although the damage was not to show until harvest. Much later, the stem-rust appeared, and since it was on the scene at the inquest, it was indicted.

3. Frost injury. The sub-freezing temperatures of the first week of April caused frost injury which was a yield factor in some parts of the State, notably in the southwestern counties. The injury appears to have been limited to Early Blackhull, the only variety which was approaching maturity at the time of the frost. Comparatively little of the wheat in the State had jointed by early April. The injury in the Early Blackhull took the form of sterility in the heads, and in some cases the straw was injured.

A condition that was common in Oklahoma wheat in 1938 was a darkening of the nodes. This was observed in many parts of the State, and to a large extent around Woodward in the northwest, where leaf-rust was light, and yields were the highest in the State. It occurred in both high-yielding and low-yielding wheats, and its presence was not correlated with yield. In fields where lodging occurred, the stems commonly broke over at the green internodes and not at the darkened nodes. In this respect the trouble appears to differ from the similar condition described by Croager in Kansas (P.D.R. 22: 242). Sections through the blackened nodes indicated that the trouble was mainly superficial, and that neither conduction nor strength of the straw appeared to be affected. This condition was probably an after-effect of the late frost, but it appears that it had little or nothing to do with the yield except in the southwestern counties, where the frost injury on the early wheat was most pronounced, and where the straw above the blackened nodes was blanched and dried.

An examination of the weather record (7) shows that the lowest temperatures during the April freeze were in the northwestern counties (Woodward County 20°-22°, Ellis County 21°, Beaver County 22°, Dewey County 20°, etc.), while the central wheat counties suffered less extreme temperatures (Grant County 24°, Garfield County 22°-27°, Kingfisher County 25°-26°, Canadian County 26°, Noble County 28°, Kay County 26°, etc.). Yet it was the northwestern counties that produced the highest yields and the central counties that suffered the more serious losses during 1938.

The type of heads and fill, as they were generally observed over the greater part of the State, presented the characteristics of slow starvation, rather than the blocking out of sterile portions in an otherwise normal head, such as follows frost injury. There would be one or two kernels to a brush, evenly over the heads, rather than two or three or sometimes four, such as Oklahoma wheat normally shows. The grains themselves would be small and light, and this property also would be evenly distributed through the heads.

It is noteworthy that yield reduction in 1938 was neither restricted to the early wheats, nor most prominent in these. As is seen in Table 1, Turkey, and other midseason wheats which were not past the tillering stage in early April, show the same poor yields as Early Blackhull. This would not be expected if frost injury was the principal cause for yield reduction.

A consideration of the foregoing points leads one to the conclusion that the April freeze was not the major factor in wheat yield and quality reductions in 1938. It undoubtedly played an appreciable part in such reductions, and in Early Blackhull wheat in the southwestern counties it may have been one of the most important yield factors, but it is not believed that this is true of the State crop generally. There has been a quite natural tendency to regard the freeze as the one important yield factor, especially on the part of crop reporters who committed themselves to a disregard of the rust potentialities earlier in the season.

4. Precipitation. The accumulated rainfall from January 1 to June 30, 1938 in Oklahoma amounted to 23.38 inches as compared with a 50-year average of 16.86 inches for the same period. While this represents an exceptionally heavy precipitation for the State it is still within the range which will permit favorable wheat growth. This moisture was fairly evenly distributed over the 6-month period. The effects of the moisture as a yield factor were exerted in opposite directions. On the one hand, it was ample to permit rapid, vigorous growth, and in this respect it was beneficial to production. On the other hand, it acted as a factor in decreasing production, generally by permitting the succulent growth and moist environment conducive to rust development, and locally by flooding or delaying the harvest.

Table 1 illustrates the common observation in 1938 that upland wheat shared to a major extent in the crop reduction. It has also been noted that leaf-rust-resistant and leaf-rust-susceptible wheats showed high and low yields respectively even when exposed to similar moisture conditions. The acreage actually involved in flooding or harvest-time water damage represented a relatively small part of the total wheat acreage.

The spring precipitation as a direct factor in wheat production was far more of a benefit than a calamity. Indirectly the reverse was true: it permitted the leaf-rust epidemic to occur, with its consequent reduction of yield, which was only partly compensated for by the vigorous growth of the wheat. (Cf. C. O. Johnston: "The leaf-rust loss probably will be underestimated owing to favorable moisture conditions which will raise the general yield level." P.D.R. 22: 180).

Conclusion

From the foregoing analysis it is concluded that the leaf-rust was the major reason for the 25 to 30 percent reduction in yield and quality of the 1938 wheat crop in Oklahoma. This conclusion is consistent with the findings of various cereal disease specialists who have studied the crop in the Southwest, and with the estimates of losses from leaf-rust as the disease followed the crop northward from Texas to the Dakotas and Canada (P.D.R. 22: 157, 176, 180, 243, 244, 369, 371).

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Appendix: Statistics of the 1938 Oklahoma Wheat Crop.

Weather Record.

	Temperature		Precipitation		Crop damage from hail	
	1937/38	Normal	1937/38	Normal	1938	1937
November	46.8	49.8	1.59	2.01		
December	38.7	39.8	1.54	1.69		
January	42.2	38.3	1.44	1.43		
February	46.4	41.0	4.45	1.37		
March	58.1	50.8	4.25	2.21	$ 97,000	$ 3,000
April	59.4	60.3	2.88	3.32	10,000	
May	68.8	68.3	5.95	4.73	741,000	293,100
June	77.1	77.3	4.37	3.80	715,000	1,505,600
					$1,563,000	$1,801,700

Production.

	1938	1937	1927-1936*
Production, in bushels	58,993,000	65,462,000	45,965,000
Acreage harvested	5,363,000	4,610,000	
Yield in bushels per acre	11.0	14.2	11.2
Market value of crop, per bushel	$.50	$1.18-$.92	
Wheat income	$29,486,000	$65,000,000	
Yield per acre, 1938 as compared with 1937	77.5%		
Test weight, in pounds per bushel	57.7	59.7-60.2	

*Includes several drought years.

Fig. 2. County map of Oklahoma, indicating the distribution of leaf-rust and other yield factors in 1938.